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## **Summary of the Hadronic Weak Interaction Session**

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### Abstract

We summarize and discuss present and future experiments on decays of light mesons and muons that were presented in the Hadronic Weak Interaction working group session of the "Workshop on Future Directions in Particle and Nuclear Physics at Multi-GeV Hadron Facilities". Precise measurements and rare-decay searches, which sense mass scales in the 1–1000 TeV region, are discussed in the context of the standard model and beyond.

### 1. Introduction

The three generation Standard Model (SM) has been very successful in explaining observed phenomena in particle physics. It presents a possible solution for the CP violation problem by having accommodated the third seemingly redundant generation into the model. However, there are many unanswered questions in the SM, *e.g.* why is there repetition of such generations, or what is the structure of the Higgs sector. Because there are many unspecified parameters and other imperfections, it is widely believed that the SM is a low-energy approximation of the ultimate theory although no confirmed experimental data are pointing in an obvious direction beyond the SM. One effective approach to find the direction is to put the SM predictions under intensive test with precision experiments and to search for forbidden decays which provide access to extremely high mass scales through virtual processes.

In order to examine the SM predictions precisely, the Cabibbo-Kobayashi-Maskawa (CKM) quark-mixing matrix as well as the top quark mass need to be determined. There could be a unitarity problem in the first-generation CKM matrix; presently  $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9957 \pm 0.0017$  [1]. This may suggest the existence of a fourth generation quark, or some other problems in the SM. Also, there are still several undetermined parameters, such as  $V_{td}$ . Following Wolfenstein [2], the CKM matrix can phenomenologically be written using four parameters;  $A$ ,  $\lambda$  (Cabibbo angle),  $\rho$  (a mixing parameter

between the first and third generations) and  $\eta$  (imaginary part which is responsible to CP violation). From existing data  $A$  and  $\lambda$  are reasonably determined to be  $1.0 \pm 0.1$  and  $0.22$ , respectively. There are very loose bounds on the  $\rho$  and  $\eta$  parameters. The branching ratios of the decay  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$  and the CP-violating decay  $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$  can be unambiguously predicted in the SM for a set of these parameters, or conversely these branching ratios can be used to determine them unambiguously. Because B meson decays provide complementary information on these parameters, the SM can be rigorously tested by combining the information gleaned from decays of  $\pi$ 's, K's and B's.

Lepton Flavor Violating (LFV) decays are forbidden in the SM. Observation of a LFV process is a clear indication of new physics [3]. Many theories beyond the SM predict the existence of LFV processes through new hypothetical particles, such as massive neutrinos in the left-right symmetric model [4], extra Higgs particles [5], leptoquarks [6] and supersymmetry partners [7]. Some predictions are very close to the present upper limits of such processes. Even if no LFV decays are seen, their upper limits will set very tight bounds on the masses of hypothetical particles.

## 2. Tests of the Standard Model

The universal coupling scheme of leptons has naturally been built into the three-generation SM, and is now studied with  $\pi$ ,  $\tau$  and  $W$  leptonic decays. The best tests of electron-muon universality  $g_e/g_\mu = 0.9985 \pm 0.0016$  come from the branching ratio of the decays  $\pi^+ \rightarrow e^+ \nu$  and  $\pi^+ \rightarrow \mu^+ \nu$  [8]. This level of precision senses the mass scale of 1–200 TeV/c<sup>2</sup> for hypothetical particles which induce pseudoscalar couplings. The new SM calculation for this branching ratio [1],  $R_{\pi \rightarrow e \nu} = (1.2350 \pm 0.0005) \times 10^{-4}$ , leaves room for improvement of the experiment almost by an order of magnitude. New experiments aiming at a precision  $\leq 0.1$  % are being discussed using better quality beams [9].

The CKM matrix element  $V_{ud}$  has been derived from superallowed  $0^+ \rightarrow 0^+$  nuclear  $\beta$ -decays, but theoretical ambiguities in nuclear wave functions and radiative corrections limit the accuracy of the matrix element determination to a level of 0.2 %. On the other hand, theoretical calculations for pion  $\beta$ -decay  $\pi^+ \rightarrow \pi^0 e^+ \nu$  do not involve nuclear wave function effects and are more reliable. Although the branching ratio is very small ( $1.025 \pm 0.034 \times 10^{-8}$ ), it is potentially a very good candidate to determine  $V_{ud}$ . There is an experiment being prepared for running at PSI [10] with the goal of a 1 % measurement based on a calorimeter consisted of 240 pure CsI crystals. The ultimate goal for the future experiments should be at a precision level of 0.1 %.

The Glashow-Iliopoulos-Maiani (GIM) mechanism, which prohibits first-order flavor-changing neutral currents and suppresses second order effects, makes decay rates very small and for certain cases almost unobservable at presently existing machines. Since the Feynman diagrams for the short-distance second-order decay modes such as the decays  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ ,  $K_L^0 \rightarrow \mu^+ \mu^-$  and  $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$  involve a virtual top quark and related CKM matrix elements  $V_{td}$  and  $V_{ts}$ , these decay modes are very sensitive to those poorly determined parameters. The decay  $K_L^0 \rightarrow \mu^+ \mu^-$  has played an important role in the understanding of flavor changing neutral currents in the context of the development of the SM. The short-distance contribution through second-order weak diagrams is expected to be small compared to long-distance effects which proceed through two virtual photons. Based on the observed branching ratio for the decay  $K_L^0 \rightarrow \gamma \gamma$ , the long-distance contribution arising from the intermediate states with two on-shell photons gives the “unitarity limit”  $6.8 \times 10^{-9}$  for the branching ratio of the decay  $K_L^0 \rightarrow \mu^+ \mu^-$ . Other long-distance effects including the off-shell photon contribution are estimated from other radiative decays of  $K_L^0$  but uncertainties are still large. Nevertheless, the branching ratio

of the decay  $K_L^0 \rightarrow \mu^+ \mu^-$  ( $6.86 \pm 0.37 \times 10^{-9}$ [11] and  $7.9 \pm 0.7 \times 10^{-9}$ [12]) has provided constraints on the undetermined SM parameters. To extract information on detailed short distance effects, it is necessary to know the contribution from dispersive effects of two intermediate state off-shell photons which is difficult to obtain theoretically. It has been suggested that a measurements of  $K_L^0 \rightarrow ee\gamma$  and form factors in  $K_L^0 \rightarrow eeee$  might allow extraction of the dispersive contribution. Also, the presence of the dominant long distance contribution requires that this mode needs to be measured at a  $\sim 1$  % level. A new experiment (E871) for a higher precision of  $K_L^0 \rightarrow \mu^+ \mu^-$  measurements, as well as the search for the decay  $K_L^0 \rightarrow \mu^\pm e^\mp$ , has started at BNL and will be described in section 4.

In the decay  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ , the contributions from long distance effects are negligible and QCD corrections are of the order of 10 % of the short range contribution. The SM prediction for the branching ratio of the decay  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$  is somewhere in the  $1 - 4 \times 10^{-10}$  [13] range depending on the undetermined parameters, particularly on the  $V_{td}$  or the  $\rho$  parameter (for small  $\eta$ ). Once the CKM matrix and the mass of the top quark have been determined, this decay mode is, perhaps, the only precisely calculable second order weak interaction which is accessible to measurements. In the BNL (E787) experiment for the search of the decay  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$  and other rare-decay modes [14], a  $K^+$  beam is stopped in an active target, which is surrounded by a tracking device and photon vetoing counters. The E787 group is currently upgrading the detector system and the beam line for a higher sensitivity using a more intense kaon beam with less pion contamination to meet the goal of the first observation of this decay mode at a sensitivity of  $10^{-10}$ . The  $\pi^+$  momentum region below the  $K^+ \rightarrow \pi^+ \pi^0$  peak has now been included in the region of the search. Ultimately, the decay mode  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$  should be measured at a precision of 10 % in order to put the SM under crucial tests. A conceptual design of future detector at a multi-GeV high intensity facility is similar to the existing E787 detector although it should have better resolutions, finer detector segmentation, and a better photon vetoing capability.

Other rare kaon processes which are presently being investigated include decays  $K^+ \rightarrow \pi^+ e^+ e^-$ ,  $K^+ \rightarrow \pi^+ \mu^+ \mu^-$ ,  $K_{L,S}^0 \rightarrow \gamma\gamma$ ,  $K_{L,S}^0 \rightarrow \pi^+ \pi^- \gamma$ ,  $K_L^0 \rightarrow \pi^0 \gamma\gamma$  and other radiative kaon decays. Long distance effects generally dominate such processes but recent successes using chiral perturbation theory to parameterize the strong interaction dynamics encourage further experimental work in this area [15].

### 3. CP and T violation

Since the discovery of CP violation, its origin has remained a mystery. In neutral kaon decays, a mixture of a CP even state  $K_1^0$  ( $\epsilon \simeq 0.2\%$ ) in the mass eigenstate  $K_L^0$  induces CP violating decays (indirect component). In addition, while superweak models predict zero, the SM predicts a non-zero direct CP violating contribution ( $\epsilon'$ ) arising from ‘‘penguin’’ diagrams ( $\Delta S = 1$ ) in the range  $\epsilon'/\epsilon = 0.1 - 0.7\%$  depending on the top quark mass. Since the direct CP violating contribution appears in the double ratio

$$\eta_{+-}/\eta_{00} = [\Gamma(K_L \rightarrow \pi^+ \pi^-)/\Gamma(K_S \rightarrow \pi^+ \pi^-)]/[\Gamma(K_L \rightarrow \pi^0 \pi^0)/\Gamma(K_S \rightarrow \pi^0 \pi^0)] \simeq 1 + 6(\epsilon'/\epsilon),$$

a precise measurement of a deviation from the unity is sensitive to the direct CP violating contribution. Taking a double ratio also allows minimizing experimental uncertainties arising from the acceptance differences and other systematic effects. Another important part of the experiment is to achieve a very low background environment, because the two  $\pi$  decay mode of  $K_L^0$  is CP-suppressed and background could be a serious source of systematic errors. Since the measurement includes photon detection, higher  $K_L^0$  momentum has been used to advantage for better mass resolution and to reduce backgrounds. A CERN experiment NA31[16] reported consistency with the SM picture of CP violation, finding a non-zero value for the ratio  $\epsilon'/\epsilon = (23 \pm 3.4(\text{stat}) \pm 6.5(\text{sys})) \times 10^{-4}$ , while Fermilab experiment E731 [17]

found  $\epsilon'/\epsilon = (7.4 \pm 5.2(\text{stat}) \pm 2.9(\text{sys})) \times 10^{-4}$  with comparable precision but consistent with zero. Higher precision experiments with perhaps  $10^7 K_L^0 \rightarrow \pi^0 \pi^0$  events are now required to make progress on the measurement of  $\epsilon'/\epsilon$ . Knowledge of systematic uncertainties must also be improved commensurately and the long learning process that has accompanied this effort has led to new experiments by the groups at CERN (NA48) and Fermilab (E832) which have aims of reaching total uncertainties on  $\epsilon'/\epsilon$  of 1 to  $2 \times 10^{-4}$ . New higher intensity beams and enhanced detectors with higher rate capabilities are being employed. Both new efforts use a two-beam approach and precision calorimetry to reduce systematic uncertainties from energy scales, calibrations, acceptance variations and accidental backgrounds for the four decay modes being studied. A similar sensitivity will be pursued at DAΦNE, a  $\phi$  factory based on an  $e^+e^-$  collider [18].

The decay  $K_L^0 \rightarrow \pi^0 e^+ e^-$  can have a component of the order of  $10^{-11}$ – $10^{-12}$  due to direct CP violation from one-photon “penguin” diagrams. There is also an indirect CP violating component due to CP state mixing. This contribution was estimated by chiral perturbation theories to be  $10^{-11}$  using the observed spectrum of the process  $K^+ \rightarrow \pi^+ e^+ e^-$ . The CP conserving contribution coming from two-photon diagrams was estimated to be  $\leq 10^{-11}$  using the branching ratio and the spectrum of the decay  $K_L^0 \rightarrow \pi^0 \gamma \gamma$ . Experimentally, there are two approaches; one is to have a high kaon-beam momentum and a good angular resolution so that a good  $\pi^0$  mass resolution and a large acceptance can be achieved. This type of experiment has been described above; the experiment at Fermilab (E731/799) is in the first stage of the search. The experiments at KEK (E162) and BNL (E845) used a lower momentum beam with a large-solid-angle good-resolution detector. The E845 group obtained an upper limit of  $5.5 \times 10^{-9}$  [19] for this decay mode but also observed a potential background coming from the decay  $K_L^0 \rightarrow \gamma \gamma e^+ e^-$ , which has the same event topology except that the calculated mass from two photons is variable ( $m_{\gamma\gamma} = m_{\pi^0}$  for the decay  $K_L^0 \rightarrow \pi^0 e^+ e^-$ ). With the most stringent cuts (a single point in the phase space) the background level was estimated to be  $10^{-11}$ , comparable to the signal level [20]. Since this physics background is unavoidable, the observation of the decay mode  $K_L^0 \rightarrow \pi^0 e^+ e^-$  would depend on background subtraction with good statistics. The ultimate feasibility of using  $K_L^0 \rightarrow \pi^0 e^+ e^-$  to reveal direct CP violation may become clear once the reactions  $K_L^0 \rightarrow \pi^0 \gamma \gamma$  and  $K_S^0 \rightarrow \pi^0 e^+ e^-$  are well studied.

The decay  $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$  is an exceptionally interesting reaction (referred to as “the Golden reaction” by Wolfenstein)[2], the observation of which could unambiguously establish the SM origin of CP violation. The branching ratio is expected to lie in the range  $0.3$ – $20 \times 10^{-11}$  where the uncertainties arise primarily from presently unknown CKM parameters and  $m_t$  [2, 21]. When  $m_t$  is known (as seems likely in the next few years), measurement of both the charged and neutral channels of  $K \rightarrow \pi \nu \bar{\nu}$  to accuracy of 10 to 20 % would provide the best possible route to determining  $V_{td}$  and its phase (or equivalently  $\rho$  and  $\eta$  in the Wolfenstein representation) free of uncertainties of hadronic matrix elements at the 20 % level. The enhancement over the decay  $K_L^0 \rightarrow \pi^0 e^+ e^-$  mainly comes from the contribution of three neutrino types. The contribution from indirect CP violation is of the order of  $BR(K^+ \rightarrow \pi^+ \nu \bar{\nu}) \times \epsilon^2 = 10^{-15}$  [22] and the CP conserving part is negligible, too. The signature of this decay mode is two photons from the decay  $\pi^0 \rightarrow \gamma \gamma$  without any other activity in the detector system. Observing this reaction presents a challenge since all particles are neutral and there is no definite kinematic constraint. The present limit from a Fermilab experiment is  $B(K_L^0 \rightarrow \pi^0 \nu \bar{\nu}) < 2.2 \times 10^{-4}$  [23]. A study done for the Main Injector at Fermilab, found a sensitivity of  $3 \times 10^{-12}$  might be achievable in the presence of background[24]. Design considerations for  $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$  experiments have also been discussed for low-energy facilities [25, 26]. At lower energies, “momentum-analyzed”  $K_L^0$  beams could provide the additional handle needed to reject backgrounds (coming primarily from  $K_L^0 \rightarrow \pi^0 \pi^0$  events). In conjunction with sub-nanosecond primary beam micro-structure, some possibilities under

consideration for KAON include using time-of-flight in secondary (e.g. broad band neutral beams) and tertiary beams (neutral kaon production via  $(\pi, K)$  reactions) to enable the momentum of individual neutral kaons to be obtained. The detector should have the capabilities of high efficiency for neutral particle detection ( $10^{-3}$  inefficiency for low energy photons) including both position and angular measurements and high time resolution ( $< 1$  ns). Due to the low decay rate and difficult experimental signature,  $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$  may only be accessible for background-free study with a super-intense kaon source.

Measurements of decay asymmetry and polarization of kaon decay products also provide tests of CP violation. Transverse muon polarization in the decays  $K_L^0 \rightarrow \pi^- \mu^+ \nu$  and  $K^+ \rightarrow \pi^0 \mu^+ \nu$ , which violate T invariance, is expected to be zero in the SM because the processes are induced by first order charged currents. Some alternate models, e.g. those with extra Higgs doublets, however, predict non-zero polarization as high as  $10^{-2}$ . The latest value  $0.0031 \pm 0.0053$  in transverse muon polarization came from the decay  $K^+ \rightarrow \pi^0 \mu^+ \nu$  [27]. A group at KEK [28] is working to lower the sensitivity to muon polarization from the same decay mode to a  $9 \times 10^{-4}$  level. The detector is designed to maintain a symmetry in order to cancel systematic effects. Using a toroidal spectrometer, a muon is momentum-analyzed and stopped in a polarimeter where the muon precesses due to the magnetic field.

Longitudinal polarization of muons from the decay  $K_L^0 \rightarrow \mu^+ \mu^-$  is expected to be of the order of  $10^{-3}$  in the SM [29]. Higher polarization at a 7 % level could occur in some models [30]. Spin-spin correlation of muons from the decay  $K^+ \rightarrow \pi^+ \mu^+ \mu^-$  is another possible indication of direct CP violation [31]. Using the detector system of E787 with a slight modification in the range measurement device, it might be possible to measure transverse muon polarization from the decay  $K^+ \rightarrow \pi^+ \mu^+ \mu^-$  at a level of 1 % [32].

An alternative approach for the test of CP violation problem comes from one of the decay modes of the  $p\bar{p}$  system, namely  $K^+ \pi^- \bar{K}^0$  (or  $K^- \pi^+ K^0$ ) with a branching ratio  $2 \times 10^{-3}$ . The decay of  $\bar{K}^0$  ( $K^0$ ) to a final state  $f$  can be tagged by a pair of  $K^+$  and  $\pi^-$  ( $K^-$  and  $\pi^+$ ). There is an interference term in the  $\bar{K}^0$  and  $K^0$  decay rates to a final state  $f$  and the asymmetry of the decay rates has a characteristic time dependence, which is a function of a CP violation amplitude  $\eta_f$  and the phase angle  $\phi_f$ . If the final states  $\pi^0 \pi^0$  and  $\pi^+ \pi^-$  are chosen,  $\eta_{00}$  and  $\eta_{+-}$  can be obtained from the time dependent asymmetry measurements and then the indirect CP violating component  $\epsilon$  and the direct component  $\epsilon'$  can be deduced. The CPLEAR group at CERN built a cylindrically symmetric detector surrounding a hydrogen target where the  $\bar{p}$  beam stops. They finished a successful engineering run and observed  $\epsilon$  in the  $\pi^+ \pi^-$  final-state system [33]. The goal of the experiment is to measure  $\epsilon'/\epsilon$  at a precision of 0.3 %, which has different systematic effects from the experiments in a  $K_{L,S}^0$  beam.

At a high intensity neutron facility, T violation can be studied using the resonance neutron capture process with the polarized neutron and target. In parity violation experiments where a small admixture of  $s1/2$  states in  $p1/2$  states is detected, there is enhancement arising from a small energy denominator and a large ratio of neutron decay amplitudes between two mixing states. This enhancement factor also applies to T-violation experiments. Although the SM predicts small polarization, the effect of an additional neutral Higgs particle could be as high as 0.1–10 %. The LAMPF experiment is aiming for a sensitivity of  $10^{-4}$  [34].

Precise measurements of the phase angle differences of  $\eta_{00}$  and  $\eta_{+-}$  will provide a sensitive test of CPT invariance. The groups studying  $\epsilon'/\epsilon$  have been working simultaneously on this subject [35]. Higher intensity neutral kaon and anti-proton beams are expected for a better sensitivity.

#### 4. Lepton Flavor Violation

According to many theoretical calculations, coherent neutrinoless  $\mu$ - $e$  conversion ( $\mu^- A \rightarrow e^- A$ ), in which the nucleus remains in the ground state, may be enhanced because of coherence of many nucleons in the nucleus; on the other hand, incoherent reactions leading to nuclear excited states are suppressed by the Pauli-blocking effect. The signature of the reaction  $\mu^- A \rightarrow e^- A$  is a peak at the energy approximately  $E_e \sim m_\mu c^2 - B$ , where  $m_\mu$  and  $B$  are the muon mass and the binding energy of the muonic atom, respectively. The present upper limit  $4.6 \times 10^{-12}$  was obtained by the TRIUMF TPC group [36], which provided tight constraints on the masses of lepto-quarks and other particles (1–300 TeV/ $c^2$ ). A new experiment at PSI (SINDRUM II) is aiming at a sensitivity of  $10^{-14}$ . The limit could be improved by orders of magnitude using a high-intensity multi-GeV accelerator and a beamline-detector system proposed by Lobashev and Djilkibaev [37].

A certain class of supersymmetry and left-right symmetry models favors the  $\mu \rightarrow e\gamma$  decay [3]. The present limit is  $4.9 \times 10^{-11}$  [38]. A new search for the decay  $\mu \rightarrow e\gamma$  is currently going on at LAMPF for the sensitivity of  $10^{-13}$  using the MEGA detector consisting of seven cylindrical wire chambers and surrounding photon detectors, which give good angular resolution between the positron and the  $\gamma$ -ray [39].

The LFV decay  $K_L^0 \rightarrow \mu^\pm e^\mp$  involving both quarks and leptons has a large available phase space and occurs at a favorable rate in many models. The major background source for the studies of the processes  $K_L^0 \rightarrow \mu^\pm e^\mp$  and  $K_L^0 \rightarrow \mu^\pm \mu^\mp$  comes from the semi-leptonic decays  $K_L^0 \rightarrow \pi^\pm \mu^\mp \nu$  and  $K_L^0 \rightarrow \pi^\pm e^\mp \nu$  with the decay-product pion subsequently decaying in flight to a muon and an unobservable neutrino. This would be a serious background especially when pions decay in an analyzing magnet and a wrong momentum is measured. In order to suppress this background, the detector system measures the momentum twice. Gas Čerenkov counters followed by a calorimeter and a muon range stack provide particle identification. The present upper limit is  $3.3 \times 10^{-11}$  [40]. The characteristics of the background to these processes (due to particle misidentification and reconstruction mistakes in the semi-leptonic decays mentioned above) are known to the level of  $10^{-13}$  from the experiments [40, 41]. In the new BNL experiment (E871) aiming at a sensitivity of  $10^{-13}$ , the tracking device has more redundancy in order to suppress pathological track fits, one of the major sources of the background. The high counting rate problem is reduced by an elaborate beam plug in the middle of the detector. In future experiments, extraction of the  $K_L^0$  beam at a large angle could reduce the fraction of photons and neutrons in the beam to almost a comparable level to the  $K_L^0$ 's and allow the detector system to take a significantly higher-intensity  $K_L^0$  beam.

Even if  $K_L^0 \rightarrow \mu^\pm e^\mp$  is absent,  $K^+ \rightarrow \pi^+ \mu^\pm e^\mp$  could occur, generated by vector or scalar currents. Experimentally, the three-body charged particle final state makes vertex reconstruction reliable and allows energy and momentum constraints to be imposed. The main potential background is due to  $K^+ \rightarrow \pi^+ \pi^+ \pi^-$  decay in which two pions are misidentified as a muon and an electron. Particle identification is very crucial to this experiment and is provided by two  $H_2$  and  $CO_2$  Čerenkov counters along with a lead/scintillator calorimeter and a muon range identifier. The recent result from BNL E777 [42] was  $B(K^+ \rightarrow \pi^+ \mu^+ e^-) < 2.1 \times 10^{-10}$  based on no observed candidate events and assuming a uniform phase space distribution. A new experiment is presently under development at BNL (E865), which incorporates a new intense 6 GeV  $K^+$  beam (7 times the previous beam intensity) and new apparatus including larger magnets, improved muon detection and finer granularity detectors. The longer larger-gap analyzing-magnet allows a 3-times larger solid-angle. The aim is a sensitivity of  $3 \times 10^{-12}$

for  $K^+ \rightarrow \pi^+ \mu^\pm e^\mp$ .

## 5. Conclusion

Searches for new processes and precise measurements of rare decays have provided key information in the advance of particle physics. As amply attested to in two dozen workshop talks addressing future rare decay experiments, this program of research can be expected to be as fruitful as in the past.

Rare kaon decays like  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$  could uniquely determine CKM parameters such as  $V_{td}$  when the top quark mass is known. Evidence of direct CP violation can be probed by precise measurement of the ratio  $\epsilon'/\epsilon$  in  $K_{S,L}^0 \rightarrow \pi\pi$  decays; the new experiments with a precision of  $10^{-4}$  proposed at FNAL and CERN may confirm the existence of direct CP violating component for the first time. However, theoretical uncertainties may hinder a quantitative interpretation. The CP violating decay  $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$  provides a clean unambiguous signal of direct CP violation and strongly constrains the  $\eta$  parameter, but is a challenge to measure. Polarization measurements of muons from the decays  $K^+ \rightarrow \pi^+ \mu^+ \mu^-$ ,  $K_L^0 \rightarrow \pi^\pm \mu^\mp \nu$  and  $K_L^0 \rightarrow \mu^+ \mu^-$  may provide complementary information on the CP violation problem. Hypothetical particles introduced by extensions of the SM result in lepton flavor violating decays such as  $\mu \rightarrow e \gamma$ ,  $\mu^- A \rightarrow e^- A$ ,  $K^+ \rightarrow \pi^+ \mu^\pm e^\mp$  and  $K_L^0 \rightarrow \mu^\pm e^\mp$ . The searches are sensitive to mass scales in the TeV/ $c^2$  region.

Progress in these important studies continues to require new and upgraded detectors and hadronic beam accelerators. Many experiments can only be done at high intensity multi-GeV facilities and it is essential to have strong initiatives in this direction to carry them out.

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